Total Intravenous Anesthesia on the Battlefield

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INTRODUCTION

The current conflicts in Afghanistan and Iraq have demonstrated the impressive advancements in warfighting technology at the military's disposal. The US military in the 21st century is an awesome warfighting machine that is continually looking to improve its capabilities. The military medical system has also displayed its robust capabilities, though there is still room for improvement. Surprisingly, the delivery of anesthesia on the battlefield is still accomplished with fairly simple gas delivery systems. Is there a better, smarter, and safer way to deliver anesthesia to our wounded warriors? Total intravenous anesthesia (TIVA) has particular application in combat medicine because it accomplishes the goal of general anesthesia while it decreases the equipment necessary to provide inhalation anesthetics. The focus of this article is to review historical milestones in combat anesthesia, develop the basic concepts of TIVA, explore some of the purported benefits, particularly in combat trauma, and briefly describe some future trends in intravenous anesthesia. The goal is to demonstrate the safety, simplicity, scientific principles, and small logistical footprint of TIVA.

COMBAT ANESTHESIA: HISTORICAL PERSPECTIVE

Throughout history, attempts have been made to allay the suffering of injured Soldiers on the battlefield. In the Middle Ages, people sought pain relief in herbs, roots, seeds, flowers, opium, mandrake, hemlock, the mulberry tree, and even the garden lettuce, among other remedies.[1] A sea sponge saturated with the juices of soporific plants became the major analgesic of the time. By the middle of the 17th century, whiskey, gin, and rum had replaced most drugs, considered unsafe since there was no way to standardize the dose, although occasionally physicians used opium.[1] Colonial surgeons relied on speed and medications such as opium, rum, or cider vinegar when available.[2] In the mid 1800s, the inhalation of ether anesthesia was recommended for military use. The first combat use of ether was by American forces in Buena Vista, Mexico, early in 1847, and then again at Vera Cruz.[3] In the US Civil War, the Army Medical Service reported employing surgical anesthesia in no fewer than 80,000 cases. Surgeons preferred chloroform most of the time, although a mixture of ether and chloroform was also described, as well as alcohol and opiates.[1] Throughout WWI and WWII, continuous advances were made to provide gas anesthetic agents to the austere conditions of the battlefield. Ether continued to be the anesthetic of choice although intravenous Thiopental gained popularity during WWII.[1] However, Thiopental fell from favor after the attack on Pearl Harbor where surgeons noted that many Soldiers who were in hemorrhagic shock died after receiving the anesthetic. New vaporizers, airway equipment, and blood transfusions for treatment of shock were other battlefield advances made during WWII.[1] Anesthetists in the Korean War exercised the added benefit of intravenous muscle relaxation with the introduction of succinylcholine and tubocurarine. In Vietnam, intravenous barbiturates (pentobarbital, secobarbital) and morphine with atropine or scopolamine were used preoperatively.[1] The induction agent of choice was sodium thiopental used with a relaxant. The most common gas anesthetic agents included diethyl ether, halothane, methoxyflurane, and nitrous oxide—oxygen in conjunction with narcotics such as morphine and meperidine.[1] The common problem faced throughout all of these historical conflicts remains today. Front line surgeries are performed in austere environments within the constraints of logistical supply trains. While attempting to provide the safest anesthetic as far forward as possible, providers are still hampered by the same question, "What do we bring to war and how do we carry it there?"

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Total Intravenous Anesthesia vs General

Total intravenous anesthesia is the method of providing general anesthesia without the use of volatile anesthetic gases. General anesthesia, whether intravenous or inhalational, is recognized as analgesia, amnesia, absence of movement and autonomic stability. With the intravenous anesthetics available today, combat trauma patients can be safely induced and maintained without the use of volatile anesthetic gases. The avoidance of inhalational agents adds a significant degree of safety on the battlefield, as intravenous anesthetics do not trigger malignant hyperthermia, whereas the inhaled gases do. Furthermore, the pharmacokinetic and pharmacodynamic properties of most modern drugs makes them very titratable and suitable for continuous infusion, even in the most austere environments. Drugs like ketamine, propofol, midazolam, and newer synthetic, short acting opioids allow for predictable pharmacokinetic modeling, making TIVA an attractive alternative on the battlefield.[4]

Physiologic advantages of TIVA include improved maintenance of hemodynamic stability and temperature conservation, particularly with ketamine. Intravenous ketamine provides dissociative anesthesia, which provides amnesia and excellent analgesia. The ketamine-induced rise in blood pressure and heart rate seen in the normotensive patient can be beneficial in the trauma patient by attenuating further hemodynamic compromise. Furthermore, the peripheral vasoconstriction caused by ketamine can decrease core to periphery heat loss.[5] Total intravenous anesthesia may also be beneficial in patients who have experienced a traumatic brain injury. In July 2005, an article in the American Society of Anesthesiologists newsletter reported that TIVA was provided to over 100 patients requiring craniotomy or craniectomy.[6] Further, the article also indicated that a decrease in mortality of 50% was reported when compared to similar neurotrauma patients receiving volatile gas anesthetics. A related study reported that the hemodynamic stimulation induced by ketamine may improve cerebral perfusion and that ketamine does not increase intracranial pressure when used under conditions of controlled ventilation and coadministration of a benzodiazepine.[7]

Compared to inhalational anesthesia, TIVA has also been shown to attenuate the body's stress response to surgery. Analyzing the complete intraoperative period at 7 event-related time points, it was demonstrated that larger plasma concentrations of stress hormones occurred in an inhalation regimen than in a TIVA regimen.[8] Propofol administration may inhibit lipid peroxidation and restore antioxidant enzyme levels in extremity surgery requiring tourniquet application.[9]

Perhaps the most documented benefits of TIVA are a reduced recovery time and reduction in the incidence of nausea and vomiting. Propofol TIVA resulted in a clinically relevant reduction of postoperative nausea and vomiting compared with isoflurane-nitrous oxide anesthesia.[10] Ozkose et al[11] reported a reduced recovery time in TIVA patients and a significantly reduced incidence in nausea, vomiting, and pain. They also concluded that TIVA patients required fewer additional drugs and showed the lowest additional costs in the post-anesthesia care unit. Hofer et al[12] demonstrated similar TIVA improvement in early postoperative patient well-being and reduced incidence in postoperative nausea and vomiting. The high-quality emergence usually seen with TIVA results in fewer interventions in the postoperative period, thus serving as a force multiplier.

Why TIVA in Combat

Even in the most austere conditions, most providers would never compromise on the monitors necessary (electrocardiogram, pulse oximetry, capnography, blood pressure monitors) to provide an anesthetic. However, space, superfluous equipment, and electricity can become issues. Furthermore, logistical resupply and disposal of waste gases are also major issues. In the current theaters of both Iraq and Afghanistan, TIVA has become a reliable alternative to general anesthesia with volatile agents. With TIVA, there is less dependency on anesthetic machines and electricity. Currently, the military fields the Narkomed M anesthesia workstation (Dräger Medical Inc, Telford, Pennsylvania) and Ohmeda PAC draw-over vaporizers (Datex-Ohmeda Inc, Madison, Wisconsin) for delivery of inhalation anesthetics in the combat zone. Both are reliable for delivery of inhalation anesthetics, but there are significant drawbacks to each. The Narkomed M is supplied in 2 containers weighing 75 kg and is rather large and bulky (see Figure 1). It requires electricity (battery back-up less than 3 hours) and compressed oxygen for continuous operation. The Ohmeda PAC vaporizer, although small, has a one-way circuit that prevents the absorption of CO_2 and recirculation of anesthetic gases, resulting in an increased use of volatile agent. Both the Narkomed M and the Ohmeda PAC require some sort of scavenging system to remove waste gases, and both are dependent on the availability of volatile agents (isoflurane and sevoflurane) from supply channels.

On the other hand, TIVA requires very little equipment to administer a general anesthetic. Whether using a bolus technique or a continuous infusion through a pump, TIVA can be employed without the use of an anesthesia machine. Basically a TIVA technique uses the same intravenous medications used for anesthetic induction continued throughout the maintenance phase of the anesthetic. Several syringe infusion pumps available on the market, (eg, Alaris (CardinalHealth Inc, Dublin, Ohio), Baxter (Baxter Inc, Deerfield, Illinois) (shown in Figure 2), Bard (C.R. Bard, Inc, Deerfield, Massachusetts)) are quick to set up, and simple to operate. Most run reliably on batteries for several hours and are easily packed in the pocket of a rucksack. Induction medications such as ketamine, propofol, and etomidate can be titrated or continuously infused throughout the maintenance phase of the anesthetic. Adjuncts such as narcotics and muscle relaxants can also be easily titrated or continuously infused. Given preemptively, scopolamine and midazolam provide sedation and amnesia with little hemodynamic compromise.[13]

Figure 1. Narkomed M anesthesia workstation at the 399th Combat Support Hospital in Iraq.

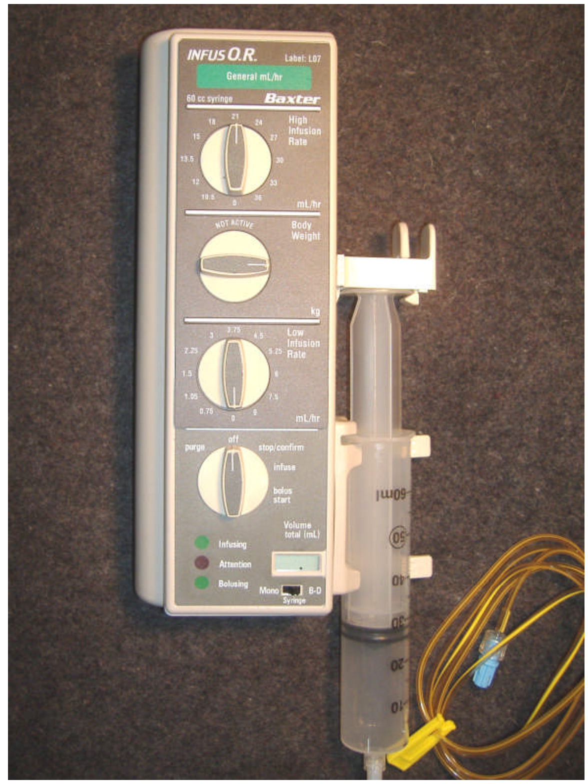

Figure 2. A Baxter syringe infusion pump.

Battlefield trauma patients often require multiple surgical interventions with intermittent intensive care stabilization. Another important benefit of TIVA over inhalation agents is that battlefield trauma patients can be maintained on the same intravenous medications, although at decreased doses, throughout the intensive care unit period. Multiple trauma patients often remain endotrachealy intubated following damage control surgery, through the resuscitation period, and often through transport to a higher echelon of care. Utilizing a continuous infusion of amnestics, hypnotics, narcotics, and muscle relaxants, patients can be transported with minimal equipment while maintaining enroute hemodynamic stability and comfort. The above advantages of TIVA in the combat setting can be summarized as the “Four Ss”: simple, safe, scientific, and a small logistical footprint.

Future Direction

Military anesthesia educational programs have recognized the importance and increasing role of

TIVA on the battlefield. In the past few years, programs for both nurse anesthetists and anesthesiologists have integrated TIVA as part of their residency training. This effort to increase the use of TIVA on the battlefield was led by the Triservice Research Group Initiative on TIVA, or TARGIT Center. The TARGIT Center has delivered thousands of total intravenous anesthetics over the past 5 years, and have shared their expertise with the global anesthesia community. The reply from the US military anesthesia community to the TARGIT Center's admirable efforts has been impressive. In 2006, the program director of the US Army Graduate Program in Anesthesia Nursing (LTC Thomas Ceremuga, oral communication, March 2008) conducted an informal survey of 105 Army and Air Force combat experienced certified registered nurse anesthetists regarding anesthesia techniques and skills. They identified TIVA as one of the top 10 areas of critical importance in the education of nurse anesthetists at the AMEDD Center and School. An article in the American Society of Anesthesiologists March 2007 newsletter reported that

> …military programs make it a requirement that all graduating residents understand the use of TIVA in both minor and major elective surgical cases during their residency, along with didactic training on the use of TIVA techniques in a combat setting.[14]

As TIVA becomes more popular, innovations in infusion pumps and delivery systems make intravenous anesthesia more practical in combat. Ongoing developments in advanced biomedical technology result in pumps that are smaller, lighter, and have extended battery life. Perhaps the most exciting innovation in TIVA administration is the target controlled infusion system currently being used in Europe (not yet approved by the US Food and Drug Administration for use domestically). It is a microprocessor-controlled syringe pump that automatically and variably controls the rate of infusion of a drug to attain a defined target medication level in the patient.[4] It is analogous to using an inhalational gas analyzer to measure delivery of volatile gas agents, but has shown a greater degree of precision and accuracy. Current infusion pumps simply deliver a preprogrammed amount and do not automatically adjust to maintain steady state anesthetic drug levels in the bloodstream. Target controlled infusers are light, compact, and show great promise for use in treating combat trauma patients. There are exciting new initiatives underway in the US military. The previously mentioned TARGIT Center was created to develop techniques and strategies that will lead to the advancement, research, education, and implementation of total intravenous anesthesia on the battlefield and in austere environments.[15]

CONCLUSIONS

The field of anesthesia has evolved tremendously from the days of ether and chloroform. Anesthetic administration on the battlefield has also evolved, with continuous efforts to minimize equipment and compensate for the effect of extremely austere environments. Many of the concerns and obstacles faced by early anesthesia providers continue to exist today. The needs for safety, rapid set up, mobility, and availability of logistical resupply are all concerns for military anesthesia providers. Intravenous general anesthesia decreases dependency on an anesthesia machine and minimizes equipment, compressed gas, and electricity requirements. Total intravenous anesthesia has emerged as a practical, reliable method of delivering anesthesia to patients injured in battle in any location. Given the safety, simplicity, scientific nature, and small logistical footprint of TIVA, the Department of Defense would be wise to consider TIVA as the battlefield anesthetic of the future.

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